Status of the SMOG2 fixed target system at LHCb

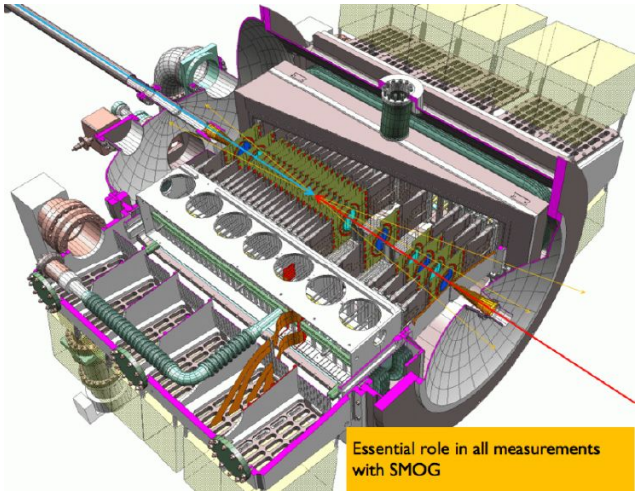
Edoardo Franzoso

24/06/2022

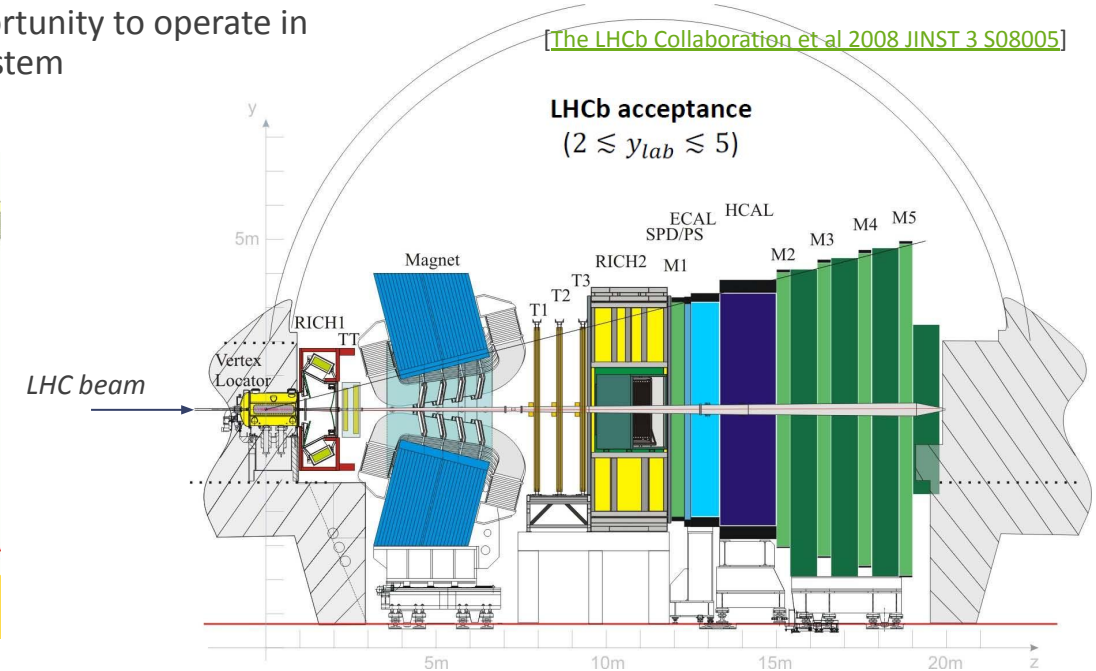
The LHCb detector is a single arm spectrometer originally designed for *heavy flavour* physics.

Its capabilities extend beyond the original expectations and LHCb is currently a ***general purpose experiment***.

Additionally, LHCb offered the unique opportunity to operate in ***fixed-target mode*** exploiting the ***SMOG*** system



[The LHCb Collaboration et al 2008 JINST 3 S08005]

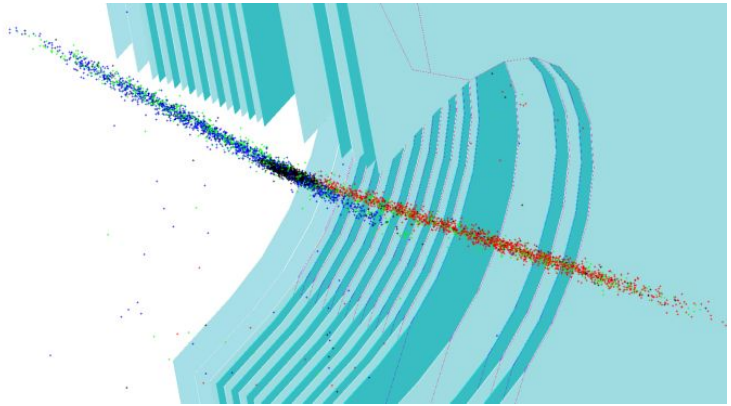


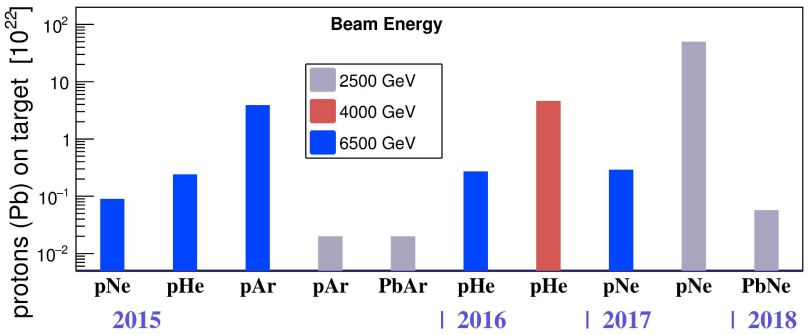
A bit of History : SMOG (System for Measuring Overlap with Gas)

Originally conceived for precise luminosity measurements (Beam-Gas Imaging) by injecting noble gases in the LHCb beam pipe in a region around the pp interaction point.

Since 2015, SMOG offered the unique possibility to perform a ***fixed-target experiment*** and to exploit the forward geometry of the LHCb detector.

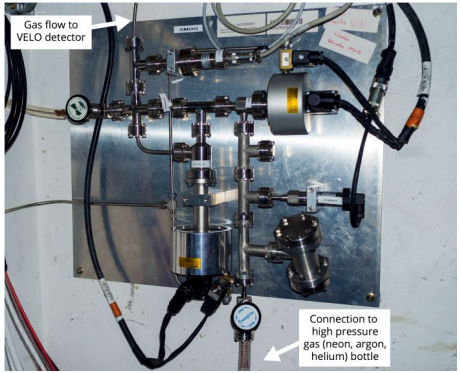
During RUN II, the SMOG program collected data in dedicated physics runs with ***multiple targets*** and at ***different energies***.





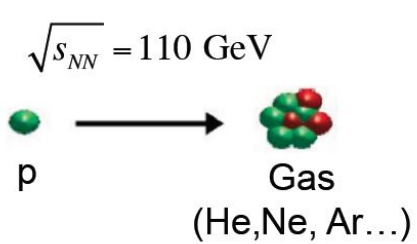
Injection System

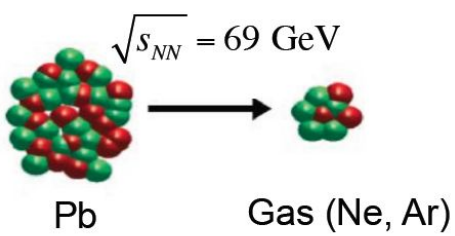
Gas injected through a ***Gas Feed System*** with a pressure of 2×10^{-7} mbar, two orders of magnitudes higher than LHC vacuum.



Kinematic conditions :

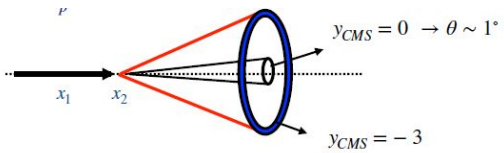
$$\sqrt{s_{NN}} = \sqrt{2E_p M_N} \in [30,\ 115]\ GeV,\ E_p \in [0.45,\ 7]\ TeV$$

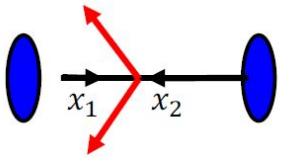




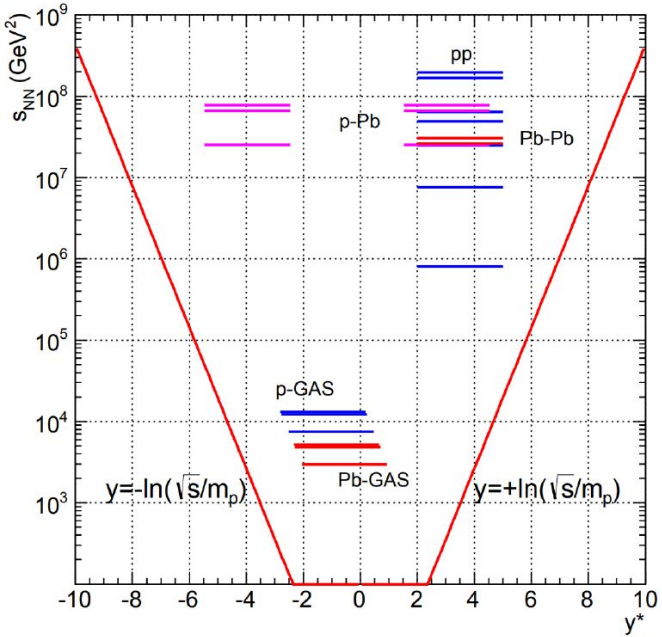
- the CM of the colliding system is strongly boosted in the lab frame → ***backward rapidity region*** in the CM frame

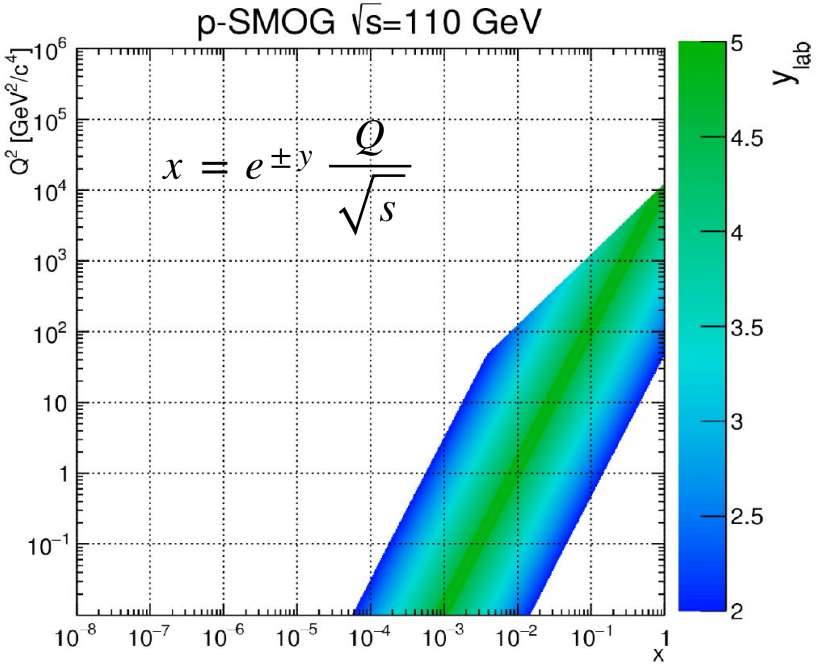
$$2 \lesssim y_{lab} \lesssim 5 \qquad \gamma = \frac{\sqrt{s}}{2m_p} \approx 60 \qquad -3.0 \lesssim y^* \lesssim 0$$





Unique access to large x values in nucleons and nuclei : $x_F = \frac{p_L^*}{|max(p_L^*)|} \sim x_1 - x_2 < 0$





Drawbacks of the LHCb Fixed Target Experiment in RUN II

Many interesting results using SMOG data (see talks by Saverio, Emilie and Frederic)

The SMOG system had some ***limitations*** :

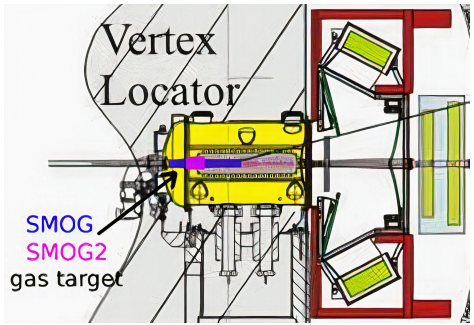
- due to the spread of the gas (± 20 m around pp vertex), only noble gases at ***low pressure*** could be safely injected

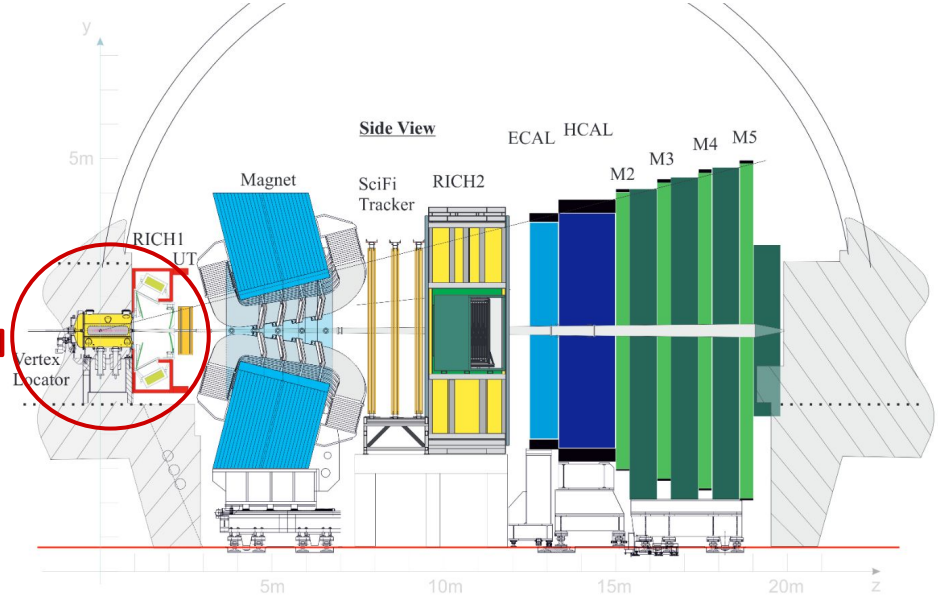
- ***gas density not known precisely*** → dominant contribution to the uncertainty related to luminosity determination through single-electron scattering

- simultaneous data taking with pp collisions not possible (overlapping of luminous region) → dedicated runs with ***limited statistics***

- ***Significant upgrades*** to the sub-detectors
- ***Full software trigger***
  - L0 (hardware trigger) removal
  - read-out of the full detector at 40 MHz

Fixed target program will profit from the improvements to the LHCb detector.

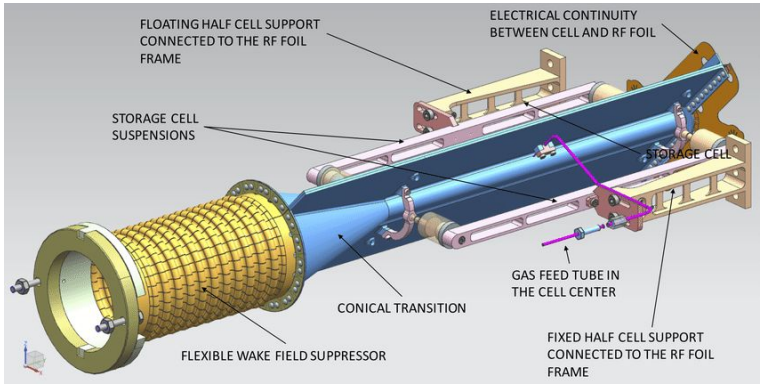


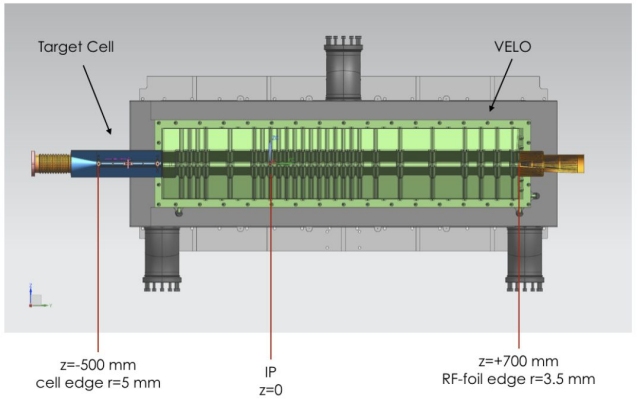


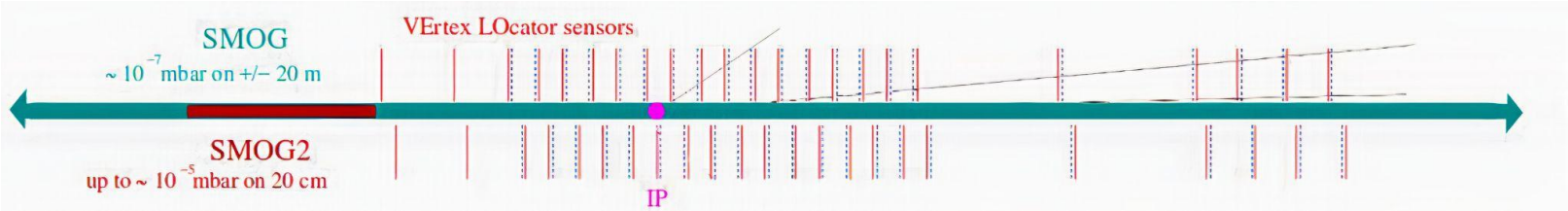
Dedicated upgrade to the fixed target program → improving its capabilities and physics reach with the installation of ***SMOG2*** [https://cds.cern.ch/record/2673690]

- Possibility to inject ***more gas species***
  - SMOG: He, Ne, Ar
  - SMOG2 : H, D, He, N, O, Ne, Ar, Kr, Xe
- Well ***displaced interaction region*** with respect to pp
- Possibility to ***run in parallel*** with collider mode

- ***Increase of target density*** (luminosity) by up to 2 orders of magnitude using the same gas flow of SMOG
- Improved Gas Feed System







Instantaneous Luminosity measurement for SMOG2

Tubular storage cell coaxial with beam → maximization of areal gas density seen by the beam

f_{rev}: beam revolution frequency
$N_{p/b}$: number of particles per bunch
N_b: number of bunches
ρ_0 : target density at the cell center
Φ: gas flow
θ : areal density
C= total conductance
D: cell diameter
L: cell length
T: temperature
M: molecular mass

Luminosity

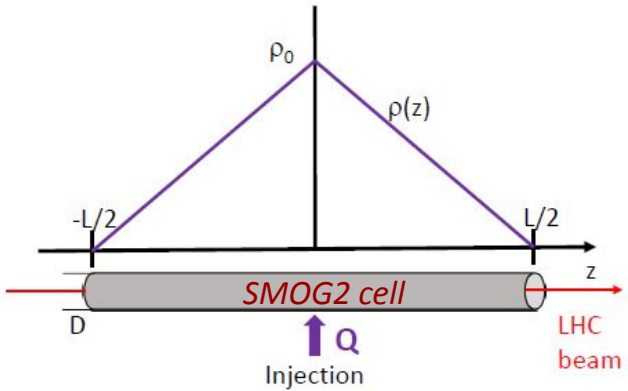
$$L_{ist} = \theta\, N_p\, f_{rev}$$

areal density

number of particles

$$N_{p/b} \cdot N_b$$

$$\rho_0 \frac{L}{2} = \frac{\Phi}{C} \frac{L}{2} \longrightarrow C = 3.81 \sqrt{\frac{T}{M}} \frac{D^3}{L + \frac{4}{3} D}$$

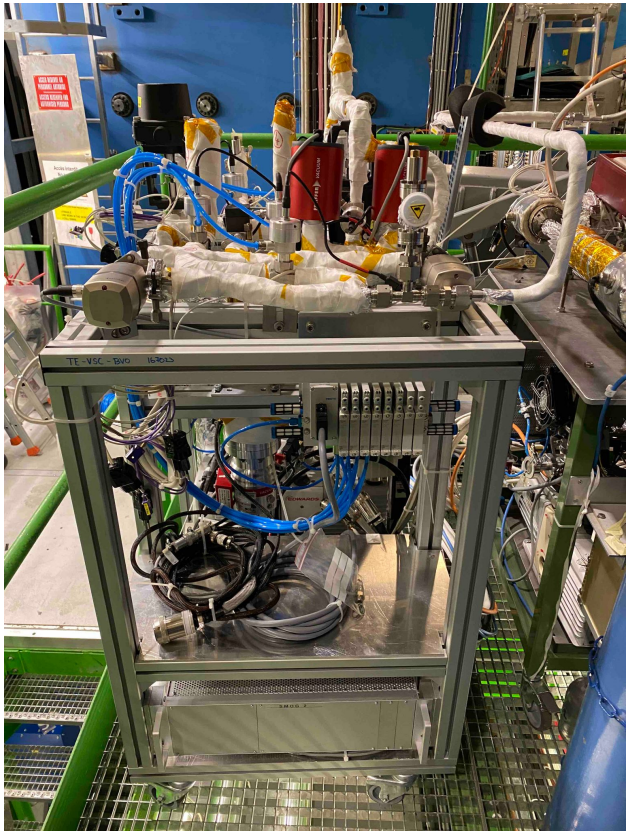


https://iopscience.iop.org/article/10.1088/0034-4885/66/11/R02

Gas species	He	Ne	Ar	Kr	Xe	H_2	D_2	N_2	O_2
SMOG2 areal density (10^{12} atoms/cm^2)	10	10	10	5	5	10	10	10	10
Intensity (10^{15} particles/s)	5.80	2.58	1.82	1.36	1.01	4.08	2.89	1.09	1.03
Flow rate (10^{-5} mbar · l/s)	21.4	9.6	6.8	4.68	3.75	15.02	10.07	4.05	3.83
SMOG areal density (10^{12} atoms/cm^2)	0.92	0.41	0.29	0.20	0.16	1.30	0.92	0.35	0.33
SMOG2/SMOG	10.9	24.4	34.5	25.0	31.3	7.7	10.9	28.6	30.3

New Gas Feed System:

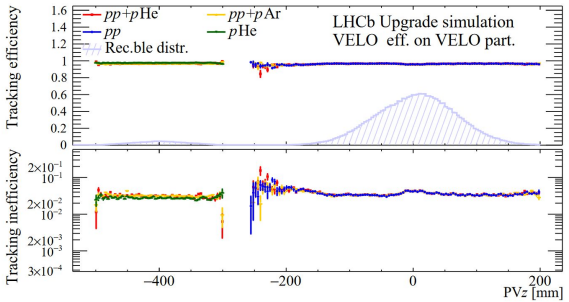
- ***precise luminosity determination ∼ 2%***
- 3 lines for noble gases and 1 for H/D
- system able to replace the gas in a short time

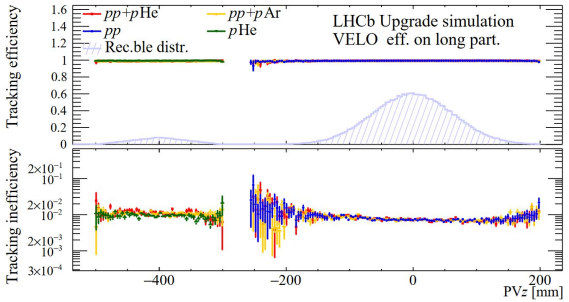


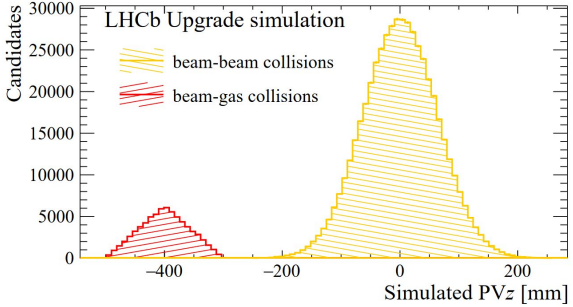
Possibility of ***simultaneous data taking*** :

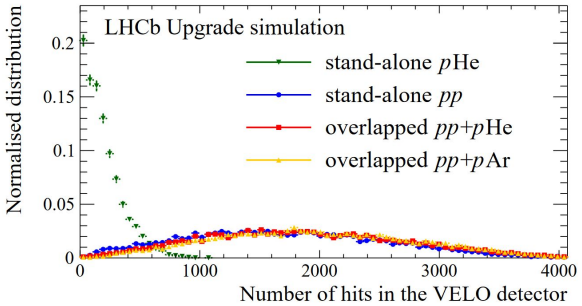
https://cds.cern.ch/record/2804589/files/LHCb-FIGURE-2022-002.pdf

- the gas presence in the cell does not affect the pp physics program
- SMOG2 reconstruction algorithms have comparable efficiencies wrt pp
- increase in processing time amounts to 1-3% with respect to beam-beam collisions only



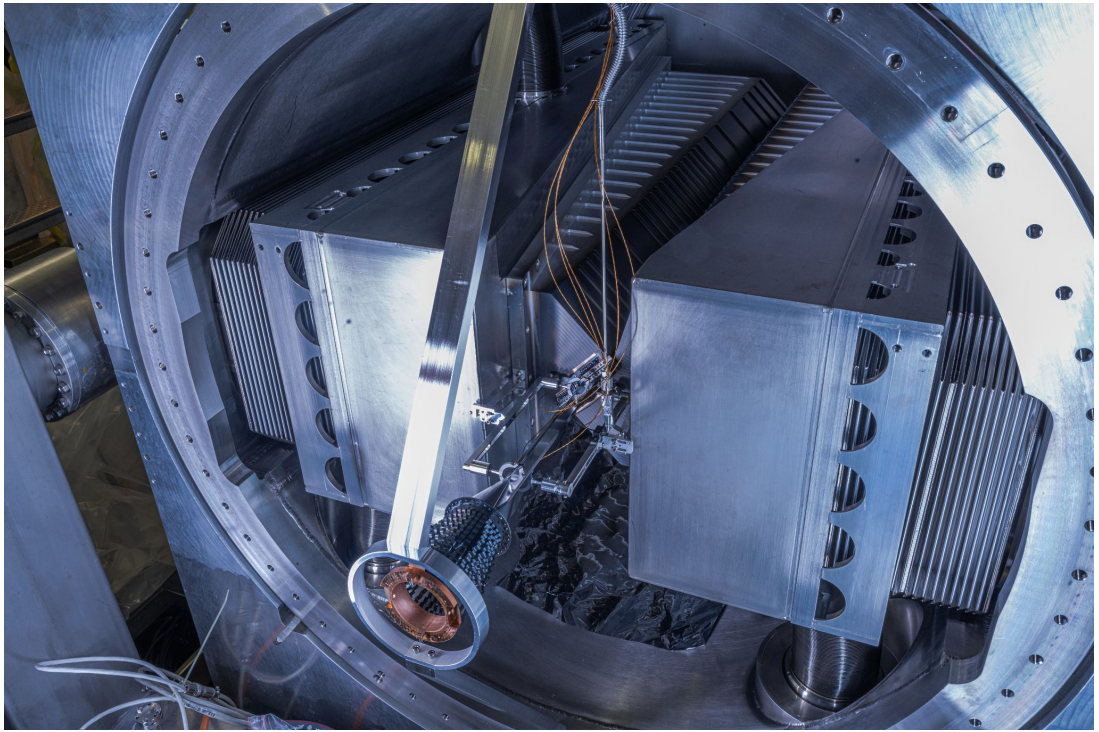






https://cds.cern.ch/record/2688875

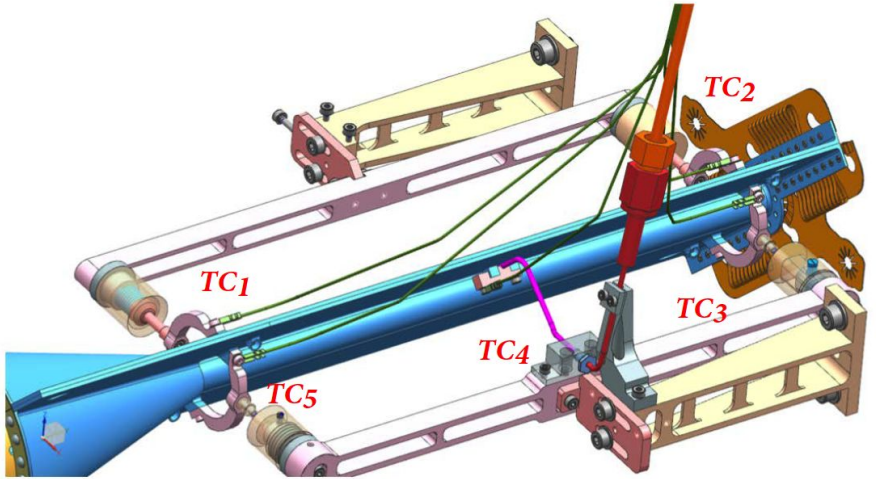
- ***storage cell installed on 08/2020***
- ***GFS installed on 03/2022***
- ***5 temperature probes***
- ***gas injected during stable beam periods***

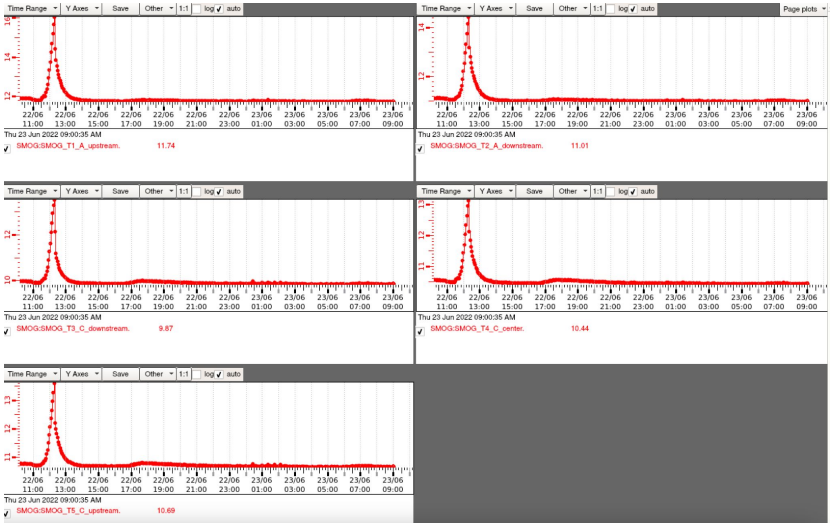


Latest news :

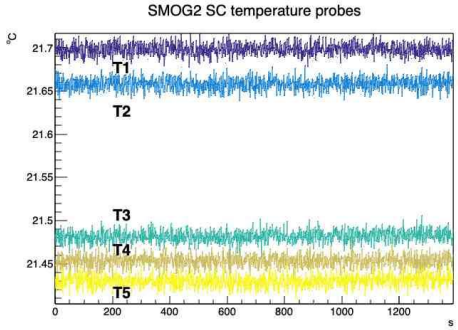
- elog
- report by Saverio here

SMOG2 Temperature probes

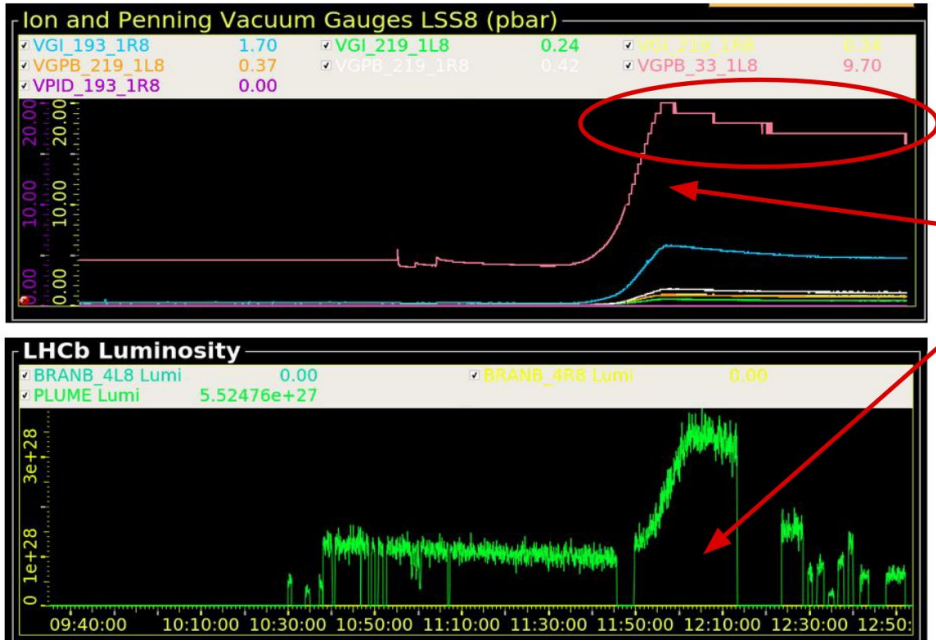




- Precise measurements
- 2 probes on A-side, 3 probes on C-side
- Calibration to be performed offline



- Ne gas injection at 11:30
- pressure monitored in real-time from the different gauges around IP8, plateau at about 8.5e-8 mbar



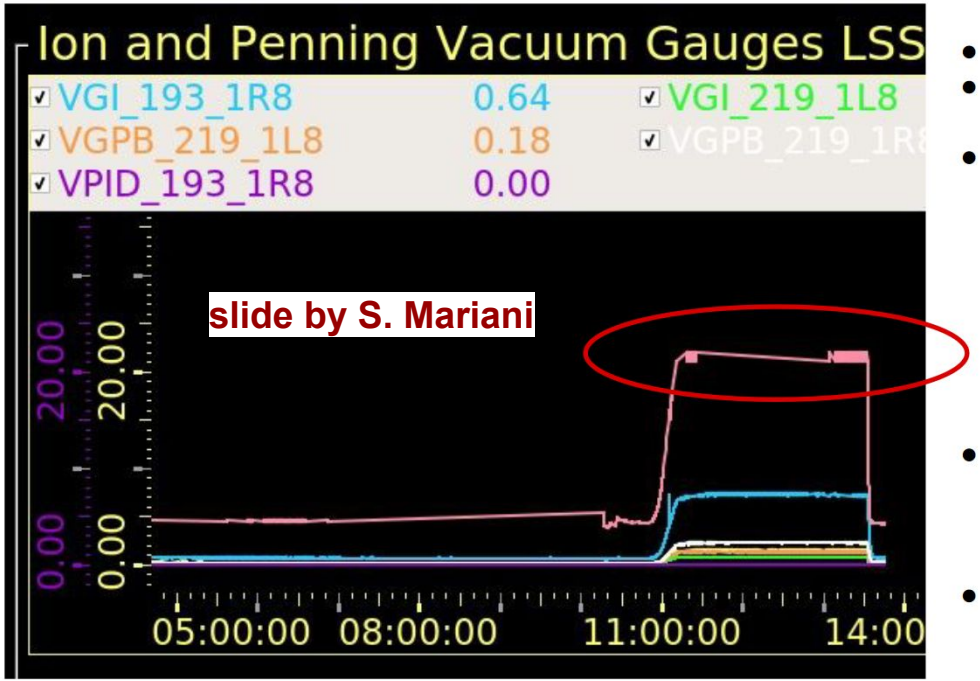
Instantaneous pressure as read from different gauges around IP8

SMOG injection

slide by S. Mariani

Instantaneous luminosity as read from the local PLUME monitoring system in bb configurations

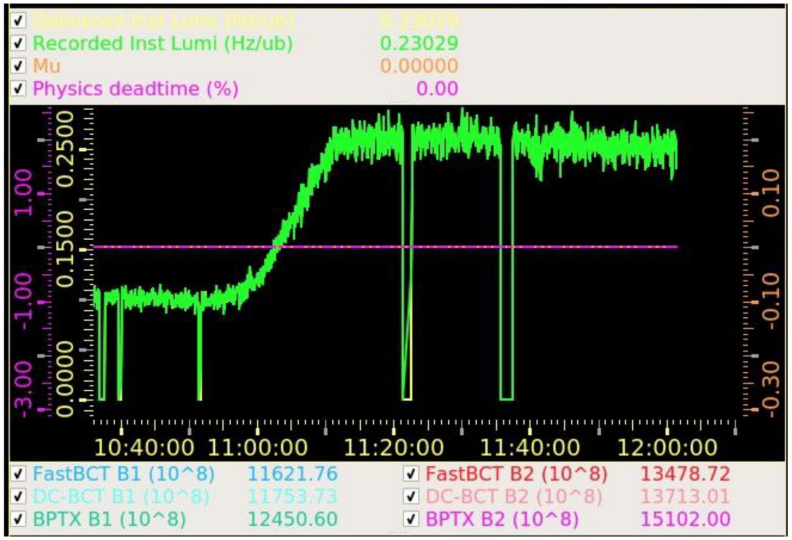
- Ne gas injection for most of the stable beam
- again a successful injection → useful validation of the procedure



- Ne Injection from 10:45 to 13:30
- A la Run2 configuration, VELO open
- Pressure plateau at 2.2e-8mbar – 2.0e-8 mbar (N_2 equivalent)

- **Very stable operation:** plateau reached in 25 minutes and kept stable. Vacuum recovery in ~30 min
- **13/06 Injection set-point VALID**

- corresponding to the gas injection, PLUME recorded an increase in the instantaneous luminosity
- CALO/RICH and MUON recorded **activity in beam-empty LHC bunch-crossing** configuration!



Conclusions and Summary

LHCb will continue a pioneering fixed-target program with SMOG2 exploiting the forward direction of the detector and its excellent performance

- unique QCD laboratory at a poorly explored √s and physically interesting kinematics regions
- potentially a wide choice of targets in combination with proton and ion beams
- the significantly higher luminosity compared to SMOG greatly increases statistics and physics reach
- LHCb is the only existing detector capable to run in both fixed-target and collider mode

Status

- Very smooth injection test operations
- Injection procedure validated
- **SMOG2 actively contributing to the commissioning**

  in synergy with the other subdetectors

Conclusions

Thanks for your attention

	SMOG published result pHe@87 GeV	SMOG largest sample pNe@69 GeV	SMOG2 example pAr@115 GeV
Integrated luminosity	7.6 nb^{-1}	$\sim$ 100 nb^{-1}	$\sim$ 45 pb^{-1}
syst. error on J/ψ x-sec.	7%	6 - 7%	2 - 3 %
J/ψ yield	400	15k	15M
D^0 yield	2000	100k	150M
Λ_c^+ yield	20	1k	1.5M
$\psi(2S)$ yield	negl.	150	150k
$\Upsilon(1S)$ yield	negl.	4	7k
Low-mass Drell-Yan yield	negl.	5	9k

- ***charmonium production*** in a QGP-free (pA) environment at energies in the $\sqrt{s}$ ~ 40 - 115 GeV range (between SPS and RHIC)
- include ***charmed baryons*** (ex. Λ_c^+)
- ***prompt beauty production***

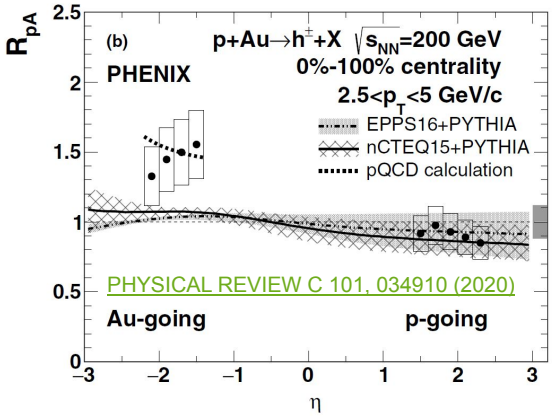
$$\Upsilon(1S) \rightarrow \mu^+\mu^-$$

- ***low-mass Drell-Yan*** measurements http://cds.cern.ch/record/1434424/?ln=it

Heavy Ions studies and Cold Nuclear Matter Effects

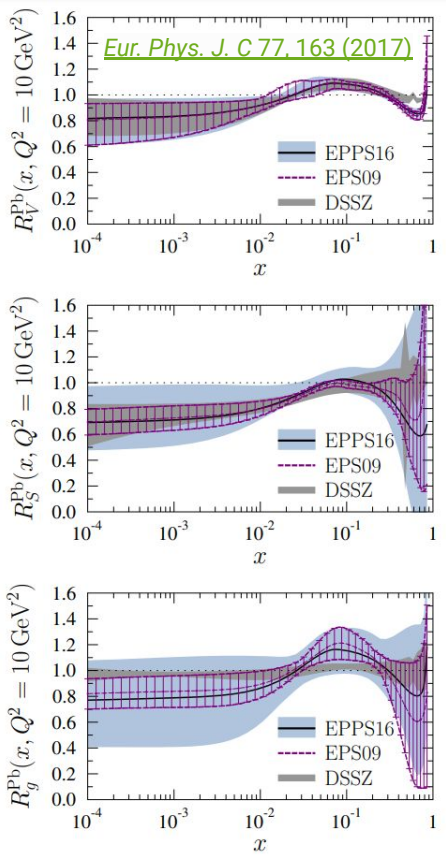
Study and disentangle effects arising from the structure of the initial state of the collision and medium-induced effects

- *Modification of the nucleon PDFs in nuclear matter*
- *High-x parton PDFs*
- *antishadowing, EMC effects*
- *Cronin effect*
- *nuclear absorption*



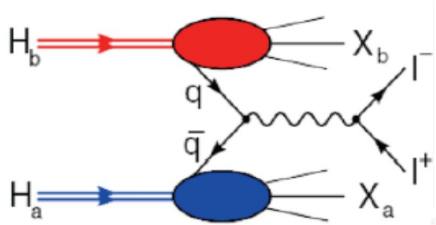
$$R_i^A(x,Q^2) = \frac{f_i^{p/A}(x,Q^2)}{f_i^p(x,Q^2)}$$

$$R_{pA} = \frac{dY^{pA}/dp_T d\eta}{dY^{pp}/dp_T d\eta} \cdot \frac{1}{\langle N_{coll}\rangle}$$

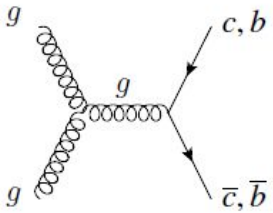


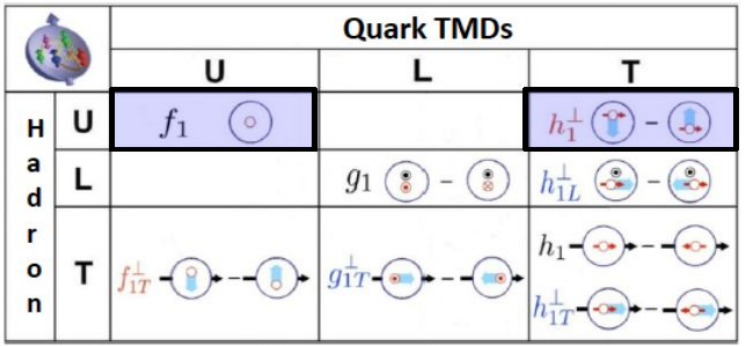
- probe quark and gluon ***PDFs*** in nucleons and nuclei, especially at high-x and moderately-high Q^2
  - Drell-Yan suitable for light quark and anti-quark PDFs in a wide kinematic region ($10^{-4} < x < 10^{-1}$)

- ***transverse momentum dependent (TDM) PDFs*** → sensitive to spin-orbit correlations inside nucleon
  - with unpolarized target look at unpolarized Drell-Yan cross section
    - sensitivity to both *u* and *d* quark contributions
    - $\sigma_{UU} \propto f_1 f_1 + \cos(2\varphi)\ h_1^{\perp}\ h_1^{\perp}$



  - gluon TMDs studies can be achieved by looking at inclusive quarkonia production (J/ψ, Υ)





Cosmic Ray Physics / Dark Matter Physics

Extend the study of antiproton production

- precise determination of the ratio

$$\frac{\sigma(pHe \to \bar{p}X)}{\sigma(pH \to \bar{p}X)}$$

- test isospin symmetry using a deuterium target